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(54) **BIOSENSOR ELECTRODE EXCITATION CIRCUIT**

**ERREGERKREIS FÜR BIOSONDENELEKTRODEN**

**CIRCUIT EXCITATEUR D'ELECTRODES DE BIOCAPTEURS**

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**EP 0 505 504 B1**

**Description****FIELD OF THE INVENTION**

This invention relates to biosensing cells and more particularly, to a circuit for reliably energizing an electrode in a biosensing cell and assuring that the electrode is properly connected.

**Reference to Related Applications**

This invention is related to inventions described in: European Patent No. 0 505 499, based on U.S. Patent application Serial No. 07/451,102, filed 15 December 1989, entitled "Regulated Bifurcated Power Supply" by Parks and White.

European Patent Application No. 91902620.3, published as WO 91/09470, based on U.S. Patent application Serial No. 07/451,212, filed 15 December 1989, entitled "Analog to Digital Conversion With Noise Reduction" by Parks.

International patent application WO 91/09373, based on U.S. Patent application Serial No. 07/451,309, filed 15 December 1989, entitled "Biosensing Instrument and Method" by White.

**BACKGROUND OF THE INVENTION**

Biosensing instruments for detecting analyte concentrations (e.g. glucose and cholesterol) are known in the prior art. Recently, an amperometric biosensor has appeared for measuring glucose concentrations in blood samples. In European Patent Application 0 230 472 to Nankai et al. and in PCT Published Application WO 89/08713 to Pottgen et al., amperometric techniques for determining glucose concentration are disclosed. Each system is dependent upon a reaction wherein glucose, in the presence of an enzyme, e.g., glucose oxidase, catalyzes a reaction of potassium ferri-cyanide to potassium ferrocyanide. After that reaction has completed, a voltage applied across the reaction zone causes the reaction to reverse with an accompanying generation of a small, but measurable, current. That current is termed the Cottrell current and, in dependence upon the concentration of glucose in the reaction zone, will follow a predetermined curve during the reverse reaction. A reading of the Cottrell current can then be converted into an indication of glucose concentration.

Various electrode configurations for applying a voltage across a reaction zone in a disposable sample card for testing fluids such as blood and the like are disclosed in US-patent 4,123,701. US-patent 4,714,874 discloses a conductive strip which is applied to a test device and used to determine the identification of the test device or the position of the test device or to calibrate an instrument which is used to read the test device.

A number of problems exist in amperometric bio-

sensors which employ the Cottrell current to provide an indication of an analyte concentration. As above indicated, the forward reaction must initially be allowed to proceed to completion before being reversed by an application of a voltage to electrodes which span the reaction zone. Thus, provision must be made to enable the on/off switching of a known excitation potential across the reaction zone. Without a known voltage being applied, current reading accuracies cannot be assured. Furthermore, since biosensors for determining the concentration of analytes such as glucose and cholesterol are often destined for home use, provision must be made for unskilled use of the instrument.

Accordingly, it is an object, of this invention to provide a voltage excitation circuit for an amperometric biosensor which enables a potential applied to the biosensing cell to be accurately determined.

It is a further object of this invention to provide a biosensing excitation circuit which provides a clear indication when a test cell is either improperly inserted or not inserted in the biosensing instrument.

**SUMMARY OF THE INVENTION**

A circuit is described for applying a potential to an electrode of a biosensing test cell, which electrode, when properly inserted in a female connector, is contacted by a pair spaced apart contacts. The circuit includes a source of excitation potential and an operational amplifier having one input connected to the source of excitation potential. A switching circuit is coupled between the operational amplifier and a first one of the spaced apart contacts, with the switch means exhibiting an impedance. A feedback circuit is connected between the second of the spaced-apart contacts and another input to the operational amplifier, to feed back a potential appearing at the second contact. The feedback is for the purpose of maintaining the output of the operational amplifier at a level which compensates for impedance losses in the switching circuit. The feedback circuit enables the output of the operational amplifier to be varied so that the potential applied to the electrode is equal to the source of excitation potential. A further circuit is connected to the feedback circuit for sensing when an open or high impedance state exists between the spaced-apart contacts.

**DESCRIPTION OF THE DRAWINGS**

Fig. 1 is a diagram of a biosensing test cell employed with this invention, illustrating its mode of insertion into a female connector.

Fig. 2 is an expanded view of one end of the test cell, indicating where its electrodes are contacted by contacts within the female connector.

Fig. 3 is a circuit diagram of the biosensing excitation circuit.

### DETAILED DESCRIPTION OF THE INVENTION

Referring now to Fig. 1, test cell 10 comprises a pair of electrodes 12 and 14 which are supported on a polymeric sheet 16. A cover sheet 18 is provided with openings 20 and 24 which expose conductors 12 and 14. Opening 20 creates a well and defines a reaction zone between conductors 12 and 14. A gel-like layer (not shown) of reactants overlays conductors 12 and 14 and provides a substrate on which a subsequent analyte-containing fluid sample can be emplaced.

A face 26 of the biosensing instrument is schematically shown having an opening 28 in which a female connector is positioned. As shown in Fig. 2, when test cell 10 is inserted in opening 28, connections are made to electrodes 12 and 14 at points A, B, and C by contacts in the female connector. After test cell 10 is inserted so that contacts A, B, and C are made, a sample of fluid containing an analyte to be measured, is placed in opening 20 and the forward reaction commences between the analyte and reactants in the reaction zone. During this period, no voltage is applied to electrodes 12 and 14 and the forward reaction proceeds to completion. Then, a potential is applied to terminal B to cause a reversal of the reaction. A reading is then taken of current flow between electrodes 12 and 14.

The circuit for applying excitation to electrodes 12 and 14 is shown in Fig. 3. Test cell 10 is schematically indicated therein, with contacts A, B, and C connected to electrodes 12 and 14. An excitation potential  $V_e$  is applied to a non-inverting input 50 of operational amplifier 52. A supply voltage  $V_s$  provides the necessary biasing for amplifier 52 and exceeds the level of  $V_e$ . The output of operational amplifier 52 is fed via switch 54 to contact B and thence to electrode 12. Switch 54 exhibits an internal impedance 56 (schematically shown) which is inserted in the circuit when control line 58 causes switch 54 to close and connect the output of operational amplifier 52 to contact B.

Contact A is connected, via conductor 60, back to an inverting input 62 of operational amplifier 52 and forms a feedback circuit which assures a circuit gain of unity. Conductor 60 is also connected via a switch 64 to an analog to digital convertor circuit 66 via conductor 68. Also connected to conductor 68, via high impedance resistor 70, is a supply voltage  $V_s$ . The closed or open state of switch 64 is controlled by an input applied via conductor 72.

As above-stated, no voltage is applied to electrodes 12 or 14 during the forward reaction time. At the termination of the forward reaction, a voltage is applied to electrode 12 which enables a current to be developed between electrodes 12 and 14. That current is fed via conductor 74, to second operational amplifier 76, where it is converted to a corresponding voltage and then provided as an output on conductor 78.

To apply the excitation voltage to terminal B, a control potential is applied via line 58 to cause switch 54 to

close (thereby inserting its characteristic impedance between the output of operational amplifier 52 and terminal B). The excitation voltage  $V_e$  applied to non-inverting input 50 of operational amplifier 52, causes the application of a voltage to terminal B which is diminished somewhat by the drop across impedance 56. Assuming that electrode 12 is properly inserted between contacts A and B, the voltage at contact B is fed back via contact A and conductor 60 to inverting input 62 of operational amplifier 52. As a result, the output of operational amplifier 52 increases towards the value of supply voltage  $V_s$ . When the feedback voltage on line 60 eventually equals excitation voltage  $V_e$ , the circuit stabilizes and the output of operational amplifier 52 is maintained at the level necessary to assure the continued application of  $V_e$  to contact B. A current thus flows between electrodes 12 and 14 and is sensed by second operational amplifier 76 and converted into a corresponding output voltage on conductor 78.

The insertion into the feedback circuit of contacts A and B, enables that circuit to also be employed to determine whether test cell 10 has been properly inserted into the biosensing instrument. If test cell 10 is improperly inserted so that electrode 12 does not make proper connection to both contacts A and B, the feedback circuit is interrupted. It can also be seen that if, for some reason, corrosion or contaminants exist which impede current flow between contacts A and B, a high impedance will occur therebetween and also cause an aberration in the feedback circuit. In either case, the level of feedback voltage applied to inverting input 62 will be greatly decreased from that which is required.

To determine that a proper voltage is being fed back, control line 72 closes switch 64 to thereby connect conductor 68 to inverting input 62 of operational amplifier 52. The closure of switch 64 also connects the supply voltage  $V_s$  (via high impedance 70) into the feedback circuit.

If a proper voltage (i.e.  $V_e$ ) is being fed back on line 60, to operational amplifier 52, then the potential on line 68 will be clamped to that level, and A to D convertor 66 will provide an output indicating that the proper excitation voltage  $V_e$  is being applied to electrode 12. On the other hand, if when switch 64 closes, a high impedance exists between contacts A and B, the potential on line 68 will rise towards  $V_s$  when switch 64 closes causing A to D convertor 66 to provide an output indicative of a problem state. (Obviously, the output of A to D converter 66 is only sampled to provide a control indication when switch 64 is closed.) Appropriate remedial action can then be taken by the control circuitry to prevent erroneous measurements.

It should be understood that the foregoing description is only illustrative of the invention. Various alternatives and modifications can be devised by those skilled in the art without departing from the invention. Accordingly, the present invention is intended to embrace all such alternatives, modifications and variances which fall

within the scope of the appended claims.

#### Claims

1. A circuit for applying a potential to a biosensing electrode (12), said electrode (12), when properly inserted in a connector, contacted by a pair of spaced-apart contacts (A,B), the combination comprising:

operational amplifier means (52) having a pair of inputs (50,62) and an output, one input (50) connected to an excitation potential ( $V_e$ ); switch means (54) coupled between said operational amplifier means (52) and a first (B) of said contacts, said switch means (54) exhibiting an internal impedance (56); feedback circuit means (60) connected between a second (A) of said contacts and a second input (62) to said operational amplifier means (52), to feed back the potential at said second contact (A) to said second input (62), whereby the output of said operational amplifier means (52) is maintained at a level which compensates for a potential drop across said switch means (54) and applies to said first contact (B) a potential bearing a predetermined relationship to said excitation potential ( $V_e$ ).

2. The circuit of claim 1 where a high impedance between said spaced-apart contacts (A,B) causes an alteration in feedback potential on said feedback circuit means (60), the combination further comprising:

signal means (64,66,68,70) connected to said feedback circuit means (60) for signalling the presence of said altered feedback potential, to indicate a malfunction with respect to said circuit.

3. The circuit of claim 2 wherein said signal means comprises:

a supply voltage ( $V_s$ );  
a high impedance (70) connected to said supply voltage ( $V_s$ );  
switch means (64) for connecting said high impedance (70) to said feedback circuit means (60); and  
sense means (66) for indicating a problem state in response to a potential at said switch means (64) whose value is near said supply voltage ( $V_s$ ), thus indicating the presence of a high impedance between said first (B) and second (A) contacts.

4. The circuit of claim 3 wherein said operational amplifier means (52) is provided with inverting (62) and

noninverting (50) inputs, and said feedback circuit means (60) is a direct connection between said second contact (A) and said inverting input (62).

5. The circuit of claim 4, wherein said electrode (12) comprises one electrode (12) of a two electrode (12,14) pluggable test cell (10), a current detector (76) being connected to the other electrode (14) of said pluggable test cell (10).

6. The circuit as defined in claim 5 wherein said pluggable test cell (10) includes a reaction zone connecting said electrodes (12,14) and enabling a current to flow therebetween in the presence of an analyte.

#### Patentansprüche

1. Schaltung zum Anlegen einer Spannung an eine Biosensor-Elektrode (12), wobei diese Elektrode (12), wenn sie richtig in ein Anschlußstück eingesetzt ist, durch ein Paar räumlich getrennter Kontakte (A,B) kontaktiert ist, umfassend folgende Kombination:

ein Operationsverstärkermittel (52) mit einem Eingangspaar (50,62) und einem Ausgang, wobei ein Eingang (50) an eine Anregungsspannung ( $V_e$ ) angeschlossen ist;

ein zwischen das Operationsverstärkermittel (52) und einen ersten (B) der Kontakte geschaltetes Schaltmittel (54), das eine innere Impedanz (56) aufweist;

ein zwischen einen zweiten (A) der Kontakte und einen zweiten Eingang (62) des Operationsverstärkermittels (52) geschaltetes Rückkoppelstromkreismittel (60) zum Rückkoppeln der Spannung an dem zweiten Kontakt (A) zu dem zweiten Eingang (62), wobei der Ausgang des Operationsverstärkermittels (52) auf einem Wert gehalten wird, der einen Spannungsabfall über das Schaltmittel (54) kompensiert und an den ersten Kontakt (B) eine Spannung anlegt, die in einer vorbestimmten Beziehung zu der Anregungsspannung ( $V_e$ ) steht.

2. Schaltung nach Anspruch 1, in der eine hohe Impedanz zwischen den räumlich getrennten Kontakten (A,B) eine Veränderung in dem Rückkoppelstromkreismittel (60) verursacht, ferner umfassend in Kombination:

ein an das Rückkoppelstromkreismittel (60) angeschlossenes Signalmittel (64,66,68,70) zum Signalisieren des Vorliegens der geänderten Rückkoppelspannung, um eine Fehlfunktion in der Schaltung anzuzeigen.

3. Schaltung nach Anspruch 2, in der das Signalmittel umfaßt:

eine Versorgungsspannung ( $V_s$ );  
eine an die Versorgungsspannung ( $V_s$ ) angeschlossene große Impedanz (70);  
ein Schaltmittel (64) zum Verbinden der großen Impedanz (70) mit dem Rückkoppelstromkreis-  
mittel (60); und  
ein Abtastmittel (66) zum Anzeigen eines pro-  
blematischen Zustands als Reaktion auf eine  
Spannung an dem Schaltmittel (64), deren  
Wert nahe der Versorgungsspannung ( $V_s$ )  
liegt, wobei das Vorliegen einer hohen Impe-  
danz zwischen dem ersten (B) und dem zwei-  
ten (A) Kontakt angezeigt wird.

4. Schaltung nach Anspruch 3, in der das Operations-  
verstärkermittel (52) invertierende (62) und nichtin-  
vertierende (50) Eingänge aufweist und das Rück-  
koppelstromkreis-  
mittel (60) eine direkte Verbin-  
dung zwischen dem zweiten Kontakt (A) und dem  
invertierenden Eingang (62) ist.

5. Schaltung nach Anspruch 4, in der die Elektrode  
(12) eine Elektrode (12) einer zwei Elektroden  
(12,14) umfassenden, steckbaren Testzelle um-  
faßt, wobei ein Stromdetektor (76) mit der anderen  
Elektrode (14) der steckbaren Testzelle (10) ver-  
bunden ist.

6. Schaltung wie in Anspruch 5 definiert, in der die  
steckbare Testzelle (10) eine Reaktionszone auf-  
weist, welche die Elektroden (12,14) verbindet und  
in Anwesenheit eines Analyten einen Stromfluß  
zwischen diesen ermöglicht.

#### Revendications

1. Circuit pour appliquer un potentiel à une électrode  
biométrique (12), ladite électrode (12), quand elle  
est correctement insérée dans un connecteur, est  
en contact par une paire de contacts espacés (A,  
B), la combinaison comprenant:

- un moyen d'amplificateur opérationnel (52)  
ayant une paire d'entrées (50, 62) et une sortie;  
une entrée (50) étant reliée à un potentiel d'ex-  
citation ( $V_e$ );
- un moyen de commutation (54) couplé entre le-  
dit moyen d'amplificateur opérationnel (52) et  
un premier élément (B) desdits contacts, ledit  
moyen de commutation (54) présentant une im-  
pédance interne (56);
- un moyen de circuit de rétroaction (60) connec-  
té entre un deuxième élément (A) desdits con-  
tacts et une deuxième entrée (62) audit moyen

d'amplificateur opérationnel (52), pour réappli-  
quer le potentiel dudit deuxième contact (A) à  
ladite deuxième entrée (62), ainsi la sortie dudit  
moyen d'amplificateur opérationnel (52) est  
maintenue à un niveau qui compense la chute  
de potentiel à travers ledit moyen de commu-  
tation (54) et applique audit premier contact (B)  
un potentiel étant dans une relation prédéter-  
minée par rapport audit potentiel d'excitation  
( $V_e$ ).

2. Circuit selon la revendication 1, où une impédance  
élevée entre lesdits contacts espacés (A,B) provo-  
que une modification du potentiel de rétroaction sur  
ledit moyen de circuit de rétroaction (60), la combi-  
naison comprenant de plus:

un moyen de signal (64,66,68,70) connecté  
audit moyen de circuit de rétroaction (60) pour si-  
gnaler la présence dudit potentiel de rétroaction  
modifié, afin d'indiquer un dysfonctionnement en ce  
qui concerne ledit circuit.

3. Circuit selon la revendication 2, dans lequel ledit  
moyen de signal comprend:

- une source de tension ( $V_s$ );
- une impédance élevée (70) connectée à ladite  
source de tension ( $V_s$ );
- un moyen de commutation (64) pour connecter  
ladite impédance élevée (70) audit moyen de  
circuit de rétroaction (60); et
- un moyen de lecture (66) pour indiquer un état  
anormal en réponse à un potentiel au niveau  
dudit moyen de commutation (64) dont la valeur  
est proche de ladite source de tension ( $V_s$ ), in-  
diquant ainsi la présence d'une impédance éle-  
vée entre lesdits premier (B) et deuxième (A)  
contacts.

4. Circuit selon la revendication 3, dans lequel ledit  
moyen d'amplificateur opérationnel (52) est prévu  
avec des entrées inverseuse (62) et non inverseuse  
(50), et ledit moyen de circuit de rétroaction (60) est  
une connexion directe entre ledit deuxième contact  
(A) et ladite entrée inverseuse (62).

5. Circuit selon la revendication 4, dans lequel ladite  
électrode (12) comprend une électrode (12) d'une  
cellule (10) d'essai enfichable à deux électrodes  
(12,14), un détecteur de courant (76) étant connec-  
té à l'autre électrode (14) de ladite cellule d'essai  
enfichable (10).

6. Circuit tel que défini selon la revendication 5, dans  
lequel ladite cellule (10) d'essai enfichable inclut  
une zone de réaction connectant lesdites électro-  
des (12,14) et permettant au courant de passer en-  
tre celles-ci en présence d'un analyte.

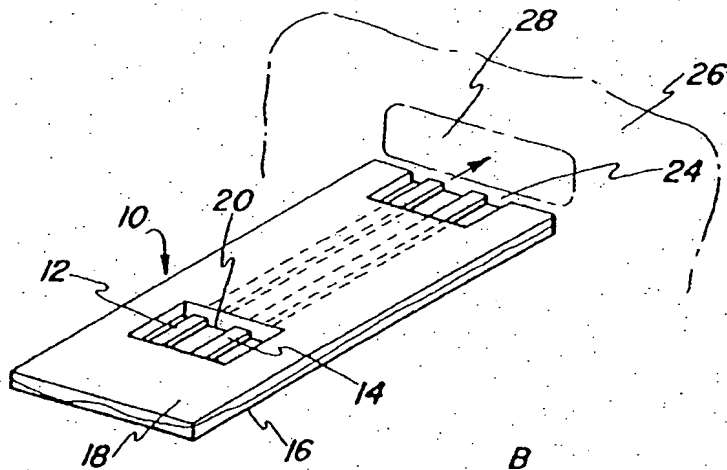


Figure 1

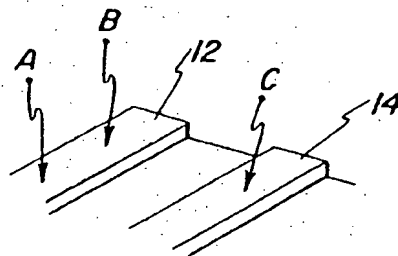


Figure 2

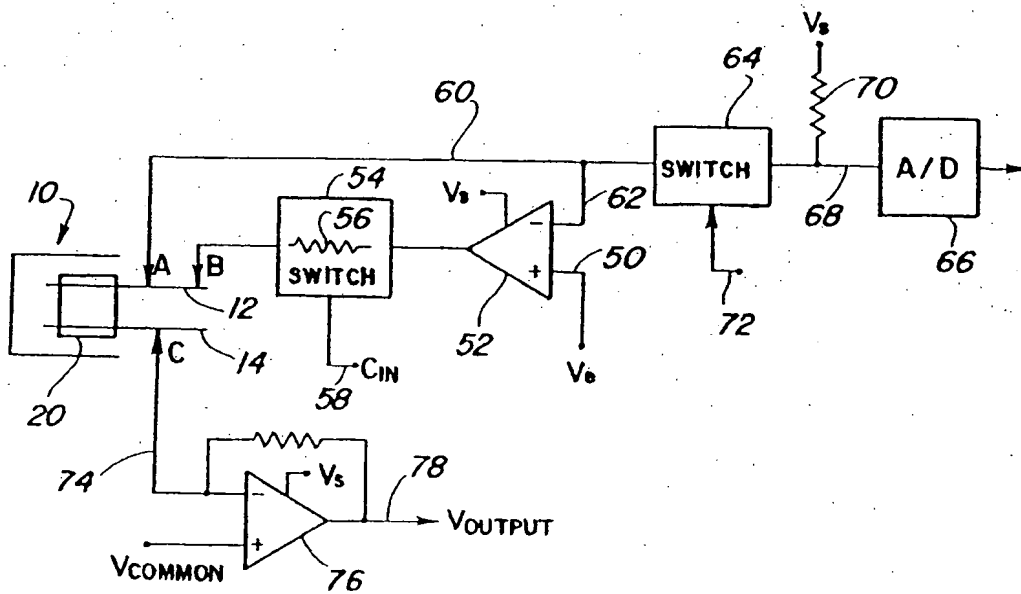


Figure 3